BUBBLE PUMP

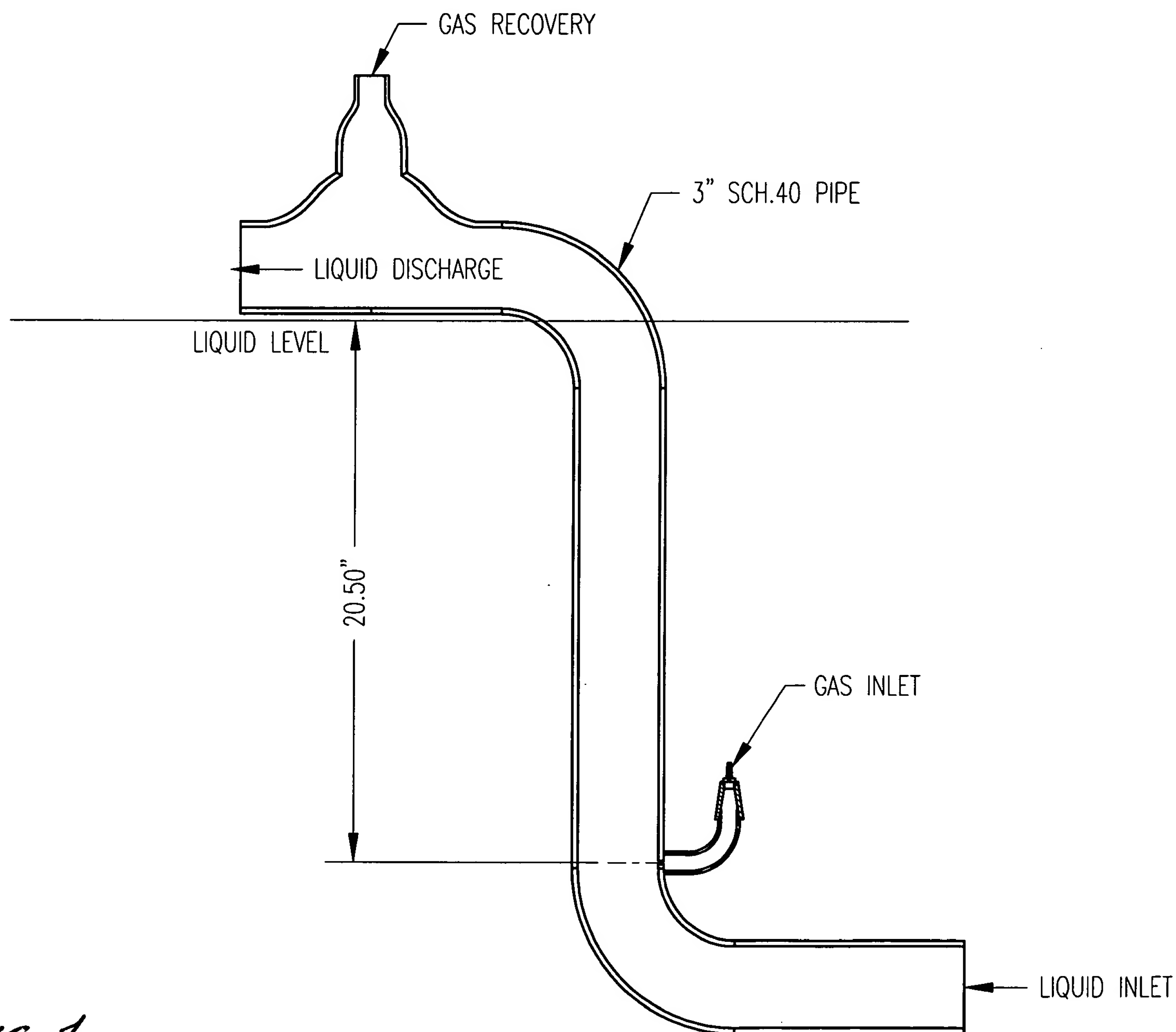

FIG. 1

DPM
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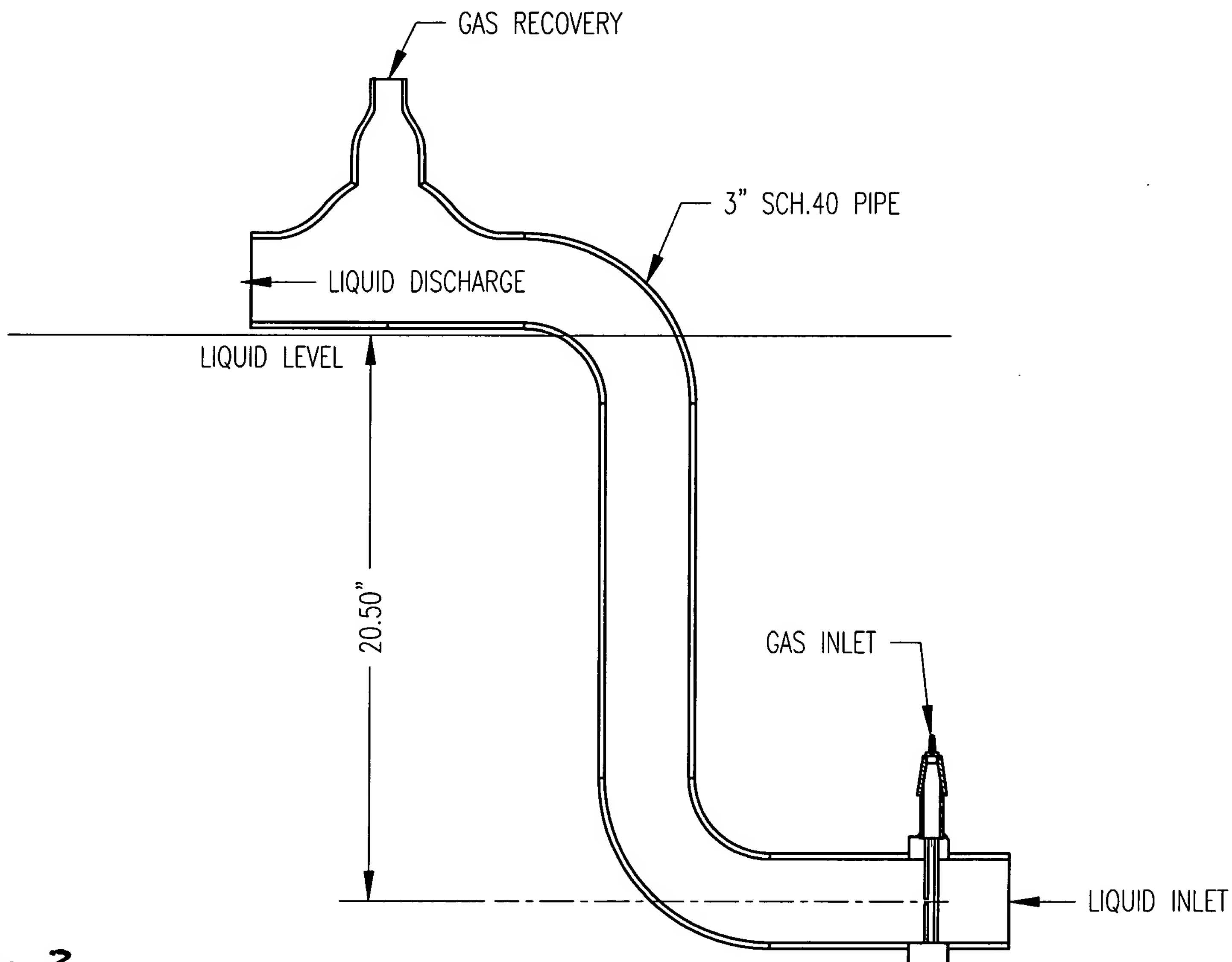
JET PUMP WITH COAXIAL GAS INLET



DPM
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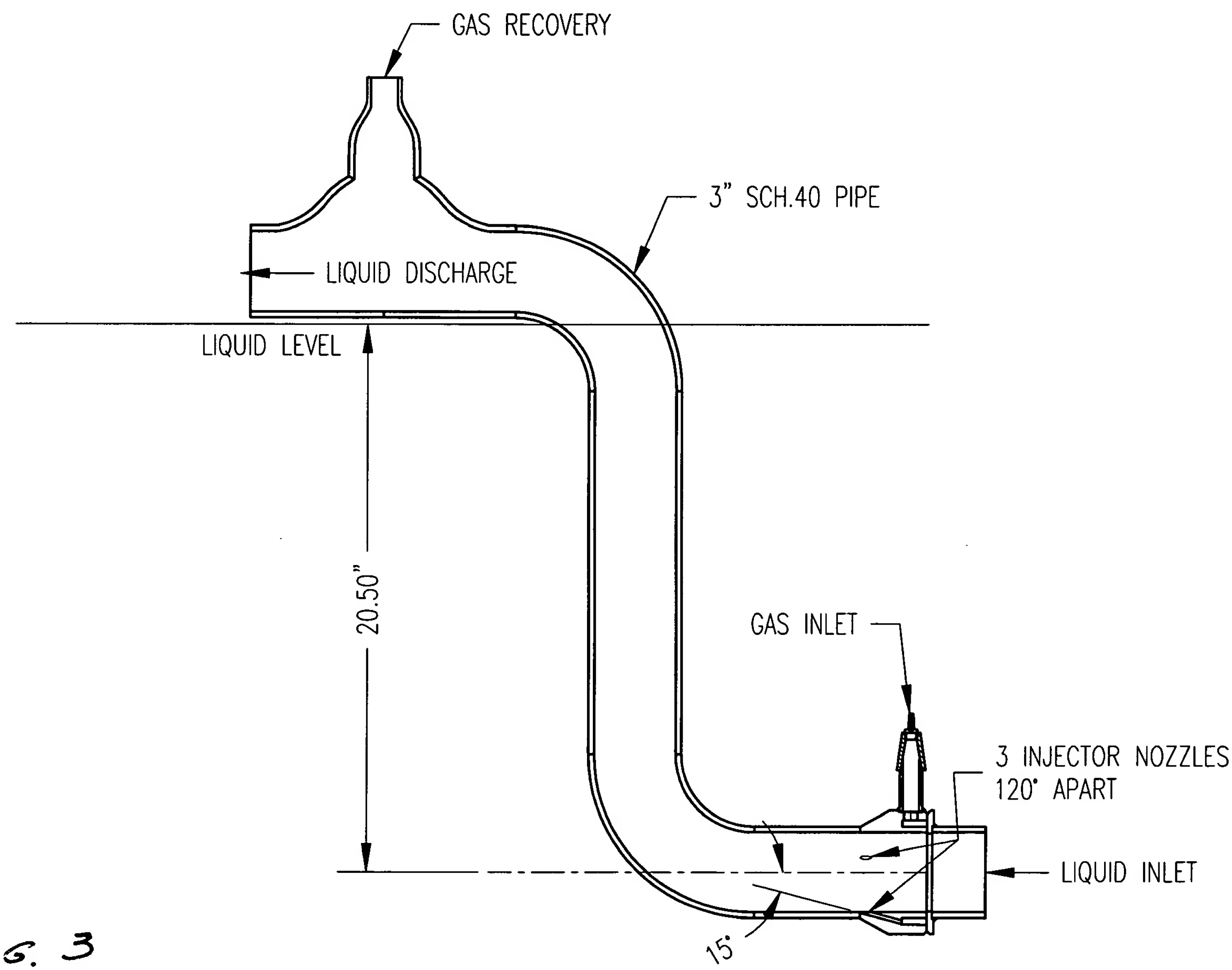
FIG 2.

JET PUMP WITH PERIPHERAL GAS INLET



DPM
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FIG. 3

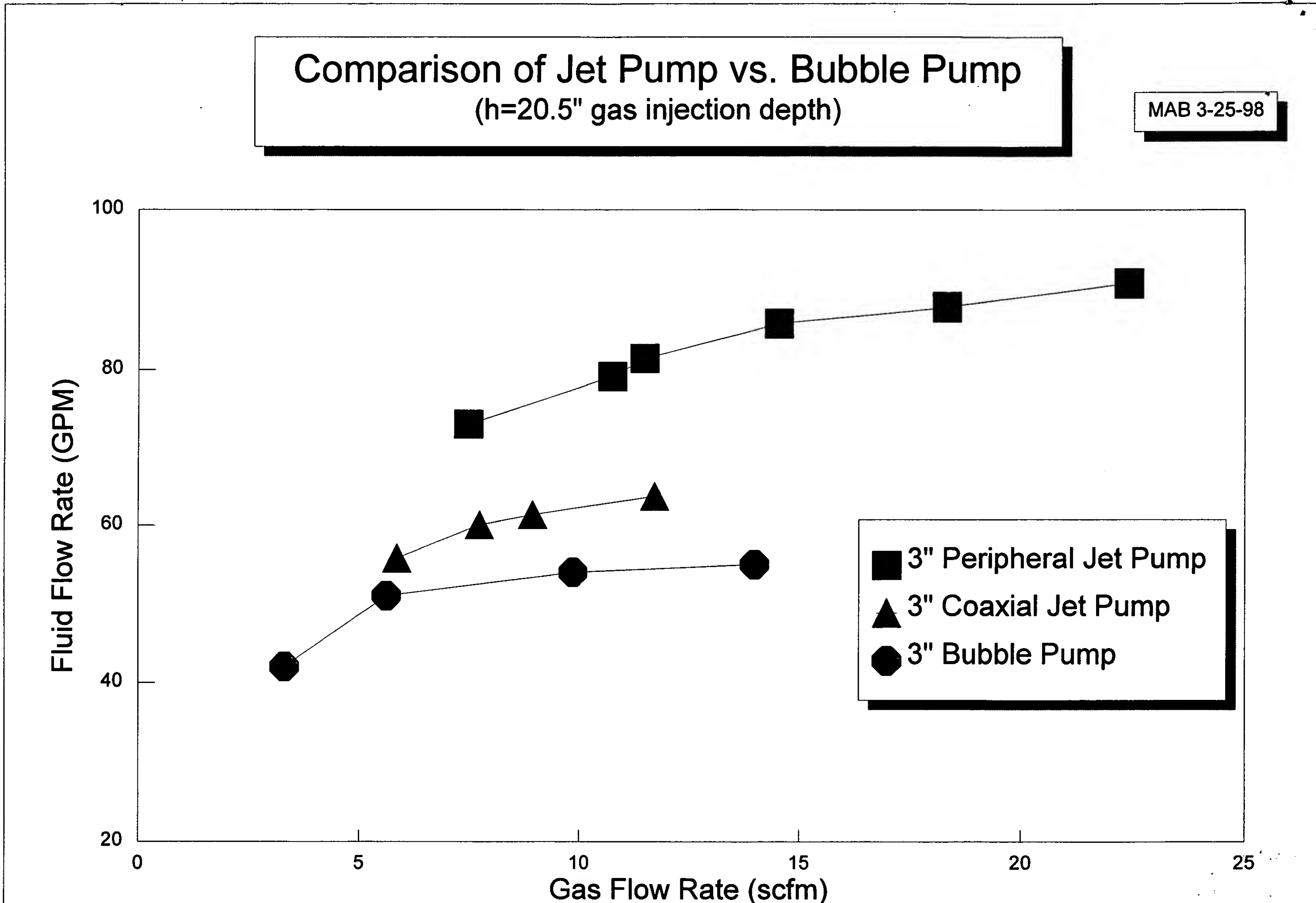
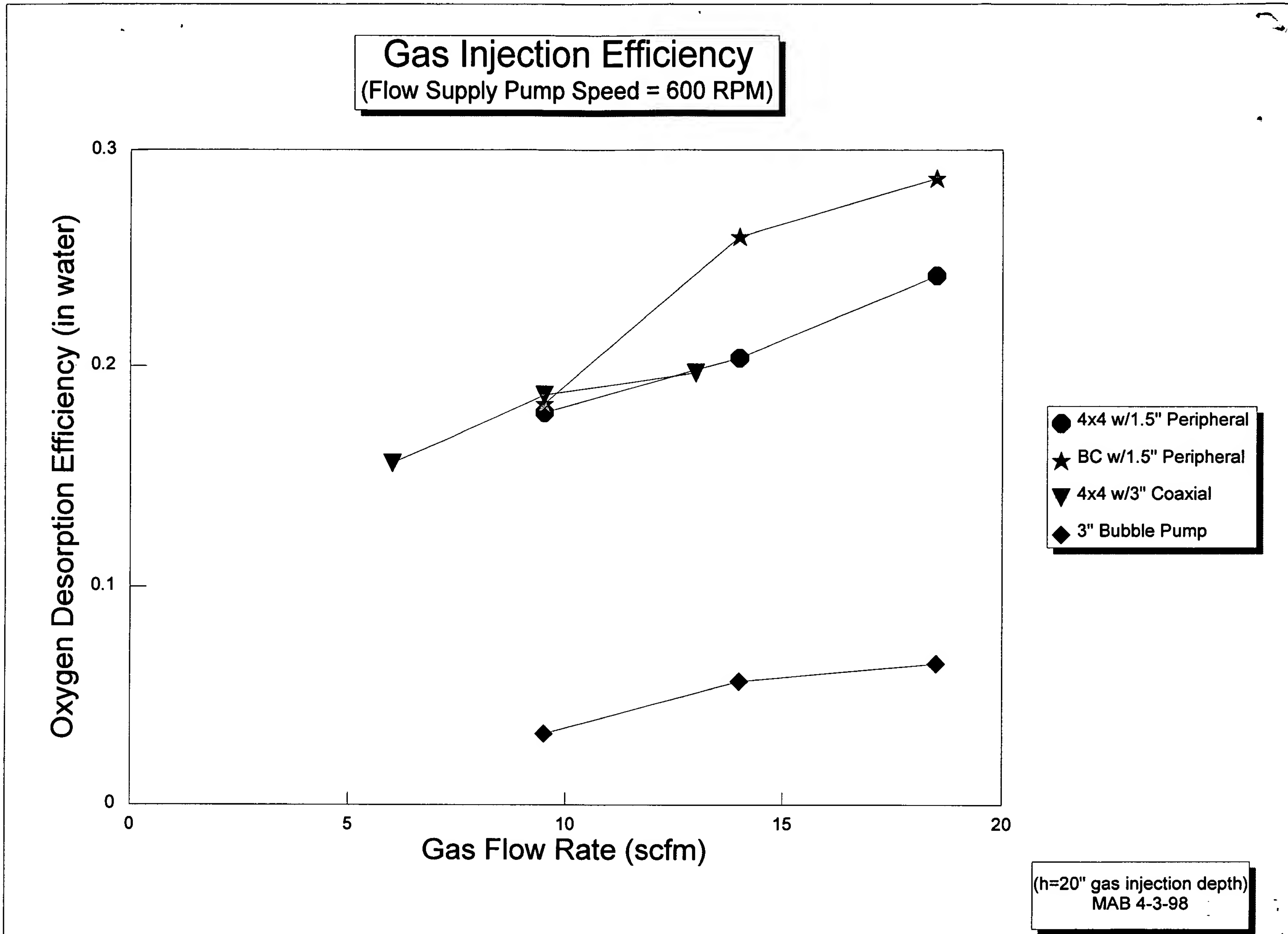
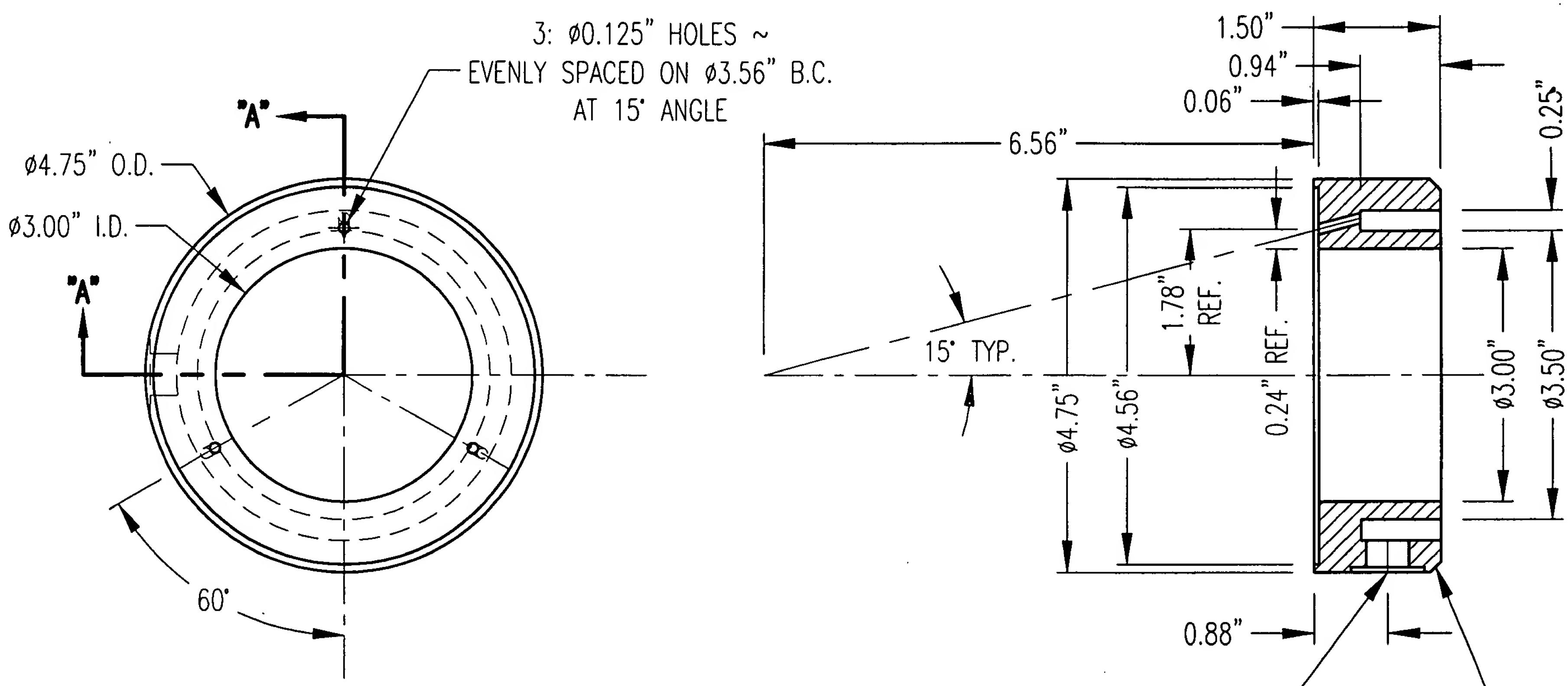

Comparison of Jet Pump vs. Bubble Pump
(h=20.5" gas injection depth)
MAB 3-25-98
Fluid Flow Rate (GPM)
100
80
60
40
20
0
5
10
15
20
25
Gas Flow Rate (scfm)
3" Peripheral Jet Pump
3" Coaxial Jet Pump
3" Bubble Pump

FIG. 4



Gas Injection Efficiency
(Flow Supply Pump Speed = 600 RPM)
Oxygen Desorption Efficiency (in water)
0.3
0.2
0.1
0
0
5
10
15
20
Gas Flow Rate (scfm)
4x4 w/1.5" Peripheral
BC w/1.5" Peripheral
4x4 w/3" Coaxial
3" Bubble Pump
(h=20" gas injection depth)
MAB 4-3-98

FIG. 5



Metaullics
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MAT'L: CARBON STEEL

SECTION A~A

FIG. 6

LTR	REVISION	DATE	ECN#

TOLERANCES UNLESS OTHERWISE NOTED

FRACTIONS = ±1/32"
DECIMALS:
.XX = ±0.03"
.XXX= ±0.030"
ANGLES = ±1°

JET PUMP BODY
3 X 0.125" DIA. JETS

Metaullics Systems Co. L.P.
Molten Metal Systems 31935 AURORA ROAD ~ SOLON, OH 44139

SCALE: 1" = 2"	DRAWN: JBT
CHECKED: LDL	DATE: 6/7/99
APPROVED: LDL	DATE: 6/7/99

310-0030-A

COMPARISON OF PHYSICAL DESIGN CHARACTERISTICS BETWEEN A BUBBLE PUMP AND JET REACTOR, COAXIAL AND PERIPHERAL GAS INJECTION PUMPS

FEATURE CHARACTERISTIC	BUBBLE PUMP	COAXIAL PAT. # 5,863,314	COAXIAL-COAXIAL FIGS. 1 THRU 14 & 17	PERIPHERAL FIGS. 15, 16, AND 19 THRU 23	COMMENTS
Gas input direction	Perpendicular to outlet flow	Coaxial with outlet flow	Coaxial with outlet flow	Coaxial with outlet flow* 0° to 15°	Coaxiality with outlet flow is almost a must to obtain some decent flow velocity. The gas generates its own convergent/ divergent fluid/gas outlet nozzle, optimizing performance.
Liquid inlet direction	Perpendicular to gas flow	Perpendicular to gas flow	Coaxial with gas flow	Coaxial with gas flow	Inlet flow coaxiality increases the pump efficiency even further.
Maximum gas velocity	Low subsonic	Sonic	Sonic	Sonic	Sonic flow reduces bubbles' diameter, increases gas residence time in the fluid, and converts pressure energy into velocity that gets transmitted to the fluid almost doubling the pump flow performance.
Energy conversion to fluid flow	Static head available - gas/flow shock losses - inlet losses	Gas pressure energy + static head - inlet fluid losses	Gas pressure energy + static head	Gas pressure energy + static head	The peripheral design provides the most energy with minimum losses and maximum gas momentum transfer to the liquid.

FEATURE CHARACTERISTIC	BUBBLE PUMP	COAXIAL PAT. # 5,863,314	COAXIAL-COAXIAL FIGS. 1 THRU 14 & 17	PERIPHERAL FIGS. 15, 16, AND 19 THRU 23	COMMENTS
Nozzle configuration	Subsonic	Sonic	Sonic	Sonic	Only possible with coaxial or peripheral nozzle orientation.
Number of nozzles	1	1 or more	1 or more	2 or more	Increased number of nozzles reduces the bubble diameter, improving degassing performance.
Number of fluid inlets	1	2 or more	1 or more	1	Simplicity of manufacture, pumping to lower fluid levels.
Inlet to outlet pressure ratio maximum	$\frac{P_1}{P_2} < 1.30$	$\frac{P_1}{P_2} < 1.72$	$\frac{P_1}{P_2} < 1.72$	$\frac{P_1}{P_2} < 1.72$	Higher permissible pressure ratios provide for larger inlet pressure range selection and flow variation selection.
Desorption efficiency (degassing)	Poor $D_O < 0.05$	Good $D_O < 0.15$	Good $D_O < 0.20$	Very good $D_O < 0.25$	D_O is a function of: a) gas velocity, b) bubble diameter, c) total gas flow. d) Bubble Residence Time (see Fig. 5).
Outlet fluid velocity (max) @ 20.5 in. head	Poor $V_O < 2.50$ ft/sec	Good $V_O > 3.30$ ft/sec	Good $V_O > 3.60$ ft/sec	Very good $V_O > 4.25$ ft/sec	See Fig. 4. This suggests that the gas momentum a liquid/gas outlet nozzle generates an increase in performance equivalent to having two bubble pumps of equal diameter.

FEATURE CHARACTERISTIC	BUBBLE PUMP	COAXIAL PAT. # 5,863,314	COAXIAL-COAXIAL FIGS. 1 THRU 14 & 17	PERIPHERAL FIGS. 15, 16, AND 19 THRU 23	COMMENTS
Saturation flow	55 GPM @ 3" diameter pipe	65 GPM @ 3" diameter pipe	70 GPM+ @ 3" diameter pipe	100 GPM+ @ 3" diameter pipe	the conduit becomes gas-saturated sooner when large bubbles are formed and their expansion reduces the fluid-to-gas volume ratio (see Fig. 4.
Pumping direction	Incline/down-up	Any direction	Any direction	Any direction	